ARGONNE HEP THEORY GROUP

OVERVIEW

C.E.M. Wagner

HEP Division

Argonne National Laboratory

- Theory at Argonne
- External Funding Awards
- HEP Community Activities
- Career Path of Postdoctoral Appointees
- Some research Highlights
- Outlook

Composition of the Group

- The HEP Theory Group has Five Permanent Staff Members:
  Ed Berger, Geoff Bodwin, Don Sinclair,
  Carlos Wagner, Cosmas Zachos.

- After several years of planning, it has recently appointed Tim Tait as a Junior Staff Member !

- The activities of the Group have been reinforced by a number of young postdoctoral appointees.

- The number of regular postdoctoral fellows supported by the HEP Division in the last years has fluctuated around three.

- Additional postdoctoral appointments, however, have been achieved by the acquisition of Grants, or by agreements between the Laboratory and the Univ. of Chicago.

University Affiliations and Teaching Activities

Members of the Group are affiliated with Universities in the Chicagoland area:

Ed Berger – Adjunct Professor, Michigan State University, since 1997.

Carlos Wagner – Associate Professor, Univ of Chicago. Joint appointment with Argonne National Laboratory, since 1999.
Teaching Advanced Classical Electrodynamics during the Spring Quarter 2003.
Introduction to Cosmology, Spring Quarter 2004.

Close relationship with the University of Chicago was used to create a collaborative effort between ANL and the Univ. of Chicago, that led to the appointments of D. Kaplan, C. Chiang, G. Servant, and Irina Mocioiu.

Research Activities

- In the last four years, the Argonne Theory Group has written well known papers in subjects as diverse as:
  - Higgs Physics at the Tevatron and the LHC
  - Heavy Quarkonia
  - Top and Bottom quark Physics
  - Extra Dimensions
  - Cosmology: Baryogenesis and Dark Matter
  - Lattice Gauge Theory
  - Formal Theory
- Many of these articles have become wel known in our community (11 articles with more than 50 citations in refereed publications; More than 20 total).
- It has also organized seven international workshops and has contributed to the formation of more than ten postdocs and students, many of whom are now professors or permanent staff members at different Universities and Laboratories around the world.

New Initiatives

- With the increased luminosity at the Tevatron Collider, the proximity of the LHC start and the new momentum on Linear Collider planning, Argonne should reinforce the Collider Physics activities.
- The addition of Tim Tait, together with Pavel Nadolsky and Csaba Balazs, all excellent young collider physicist, is a move in that direction.
- More emphasis on Cosmology and Astroparticle Physics: Work on Baryogenesis and Dark Matter by C. Balazs, A. Menon, D. Morrissey, G. Servant and C.W. is evidence of this new initiative. The addition of I. Mocioiu, working on neutrino astrophysics, will significantly add to that effort.
- The Theory Group continues its activities on Beyond the Standard Model Physics and wants to start a more ambitious program on Neutrino Physics. Group attempted to hire A. de Gouvea and J. Beacom jointly with the Univ. of Chicago, and continues being interested in hiring a young neutrino theorist.

Theory at Argonne

- Effort is being made to increase the visibility of the group through the organization of workshops and meetings.
- Since May, 2003, members of the group have organized: Workshop on QCD on Extreme Environments, June 29–July 3, 2004, http://www.hep.anl.gov/dks/qcdxe/ Workshop on Supersymmetry, Extra Dimensions, and Higgs Bosons, May 24–28, 2004 , http://gate.hep.anl.gov/berger/ANLWorkshop2004/ Workshop on Branes and Generalized Dynamics, October 20–24, 2003, http://www.hep.anl.gov/czachos/ANLworkshop.html Workshop on Trends in Neutrino Physics, May 12–16, 2003 , http://www.neutrinooscillation.org/trends.html
- There is also an effort to increase interactions among different theory groups at ANL : Ed Berger organized a February 16, 2004 Argonne Lab-wide Theory Afternoon.
- Ed Berger is the Co-Director of the LDRD funded Argonne Lab-wide Theory Institute.

Recent ANL and External Funding Awards

- Argonne Theory Institute 2004

  Supersymmetry, Extra Dimensions, and Higgs Bosons

  $20K awarded to E. Berger and C. Wagner, to organize a workshop to take place May 24–28, 2004.

- Argonne Theory Institute 2004

  QCD in Extreme Environments

  $10K awarded to D. Sinclair, to organize a workshop to take place on June 29–July 3, 2004.

- Argonne Theory Institute 2003

  Trends in Neutrino Physics: $20K awarded for a workshop May 12–16, 2003.

- Laboratory Graduate Student Program: Support for D. Morrissey, to do his thesis under the supervision of C. Wagner at the Theory Group of the HEP Division, $24K per year, renewed for a second year.

- Argonne Individual Investigator Award, October 2001, “Extra Space-Time Dimensions ”, $ 57 K awarded to E. Berger and C. Wagner. Supported the appointment of B. Murakami for two years.

Career Paths

Among the postdocs who worked at Argonne in the last ten years, many have been hired by Laboratories:

J. Hewett (1993), Faculty at SLAC; S. Mrenna (1999), Junior Faculty at Fermilab; Z. Sullivan (2001), T.M.P. Tait (2002), Postdocs at Fermilab; J. Campbell, Fellow at CERN (2004)

Other recent postdocs obtained Positions at Universities
I. Knowles (1993), Glasgow U; R. Kauffman (1993) Muhlenberg College; C. Coriano (1995), Lecce U; S. Kim (1995) Sejong U; M. Klasen (1999) Grenoble U.; B. Harris (2001), Robert Morris U; D.E. Kaplan (2001), John Hopkins U; G. Servant (2003), Saclay; C.W. Chiang (2003), Nat. Central U, Taiwan; J. Lee (2003) Korea University; J. Jiang, Postdoc at Oregon U. (2004)

Some of them, explore other career paths, including
L. Gordon (1997), M. Wusthoff (1997);
H. Contopanagos (1997), J. Lagae (1999), A. Petrelli (1999), G. Chalmers (2001).

High Energy Physics Community Activities in the past year

Members of the Group have taken part in numerous organizing activities and have been members of various HEP groups:

Edmond L. Berger

- Organizer, Aspen Winter Conference on Particle Physics, "Where We Are and Where We Are Going", Aspen Center for Physics, Aspen, CO, February 1–7, 2004. (http://gate.hep.anl.gov/berger/Aspen04)
- Co-Organizer, 2004 Theory Institute on Supersymmetry, Extra-Dimensions, and Higgs Boson Physics, Argonne National Laboratory, May 24–28, 2004. (http://gate.hep.anl.gov/berger/ANLWorkshop2004)
- Organizer, Argonne Lab-wide Theory Afternoon, Argonne National Laboratory, February 16, 2004.
- Member, Committee on International Scientific Affairs (CISA), American Physical Society, 2003–.
- Member, Andrew Gemant Award Committee, American Institute of Physics, 2002–.
- Member, American Linear Collider Working Group, 2002–.
- Member, Coordinated Theoretical Experimental Project on QCD (CTEQ) Collaboration
- Scientific Advisory Board, Argonne National Laboratory Theory Institute, 2003–.

- Scientific Program Organizing Committee, XXXIXth Rencontres de Moriond, QCD and High Energy Hadronic Interactions, La Thuile, March 28–April 4th 2004.
- Organizing Committee and Convener of the session on the Polarized Gluon Density, Fourth Circum-Pan-Pacific Symposium on High Energy Spin Physics Univ. of Washington, Seattle, August 4–7, 2003.
- Organizing Committee, 8th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2003), New York, May 19 - 24, 2003.
- Co-organizer, Argonne Theory Institute on Trends in Neutrino Physics, May 12 - 16, 2003.
- Leader, North American Node, Quarkonium Working Group, QWGNET 2003.
- Scientific Program Committee, Vth Rencontres du Vietnam, Hanoi, Vietnam, August 6–11, 2004.
- Organizing Committee, 9th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2005), 2005
- Steering Committee, International Conference on Flavor Physics 2005, (ICFP 2005), Taiwan.

Geoff Bodwin:

- Member, Local Organizing Committee, LATTICE 2004, the XXII International Symposium on Lattice Field Theory, Fermilab, June 21–26, 2004.
- Convener, Production Section, Quarkonium Working Group QWGNET Proposal to fund a Marie Curie Research Training Network on Heavy Quarkonium 2003–present.
- Member, Local Organizing Committee, Second International Workshop on Heavy Quarkonium, Fermilab, September 20-22, 2003.
- Member, Quarkonium Working Group 2002–present.
- Member, Working Group on Heavy Flavors, Workshops on Hard Probes in Heavy Ion Collisions, CERN, 2001–2003.

Don Sinclair :

- Member of NERSC users group executive committee (NUGEX).
- Member of the Quarkonium Working Group.
- Member of the Lattice SciDAC project.
- Member of the local organizing committee for Lattice2004, Fermilab.
- Organizer of Workshop on QCD in Extreme Environments.

Carlos E.M. Wagner :

- Co-oganizer, with J. Terning and D. Zeppenfeld, TASI lectures 2004, “Physics in D $\geq$ 4”, Boulder, CO, June 2004
- Co-Organizer, 2004 Theory Institute on Supersymmetry, Extra-Dimensions, and Higgs Boson Physics, Argonne National Laboratory, May 24–28, 2004. (http://gate.hep.anl.gov/berger/ANLWorkshop2004)
- Co-organizer, with Wilfried Buchmuller and Gordy Kane, Workshop on Baryogenesis, Univ. of Michigan, Ann Arbor, June 2003.
- Co-organizer, with Ed Berger and Maury Goodman, Argonne Theory Institute on Neutrino Physics, May 12 - 16, 2003.
- Co-organizer, with Cosmas Zachos and Tom Cultright, Argonne Theory Workshop on Branes and Generalized Dynamics, October 20-24, 2003.
- Member, American Linear Collider Physics Group, 2002–

- Member, Long Range Planning Group, 2003–2004
- Member, 5-year HEP Division Review Committee, Nov. 2003.
- Member, LEP Higgs Working Group, 1996–
- Head, Theory Group, HEP Division, Sep. 2002–

Cosmas Zachos

- Principal Organizer of the Argonne HEP “Branes and Generalized Dynamics Workshop”, October 20-24, 2003, and Editor of its E-proceedings, http://www.hep.anl.gov/czachos/ANLworkshop.html
- Member of the Advisory Panel of J Phys A: Math Gen (IOP).
- Member of the Organizing Committee for the 2004 Coral Gables Conference, [CGC 2004], 15 - 19 December, Key Biscayne, Florida ”Celebrating 40 Years of Quarks and Coral Gables Conferences”
- External Ph D Thesis Examiner for J G Wood, Univ of Queensland, Australia

Research Highlights

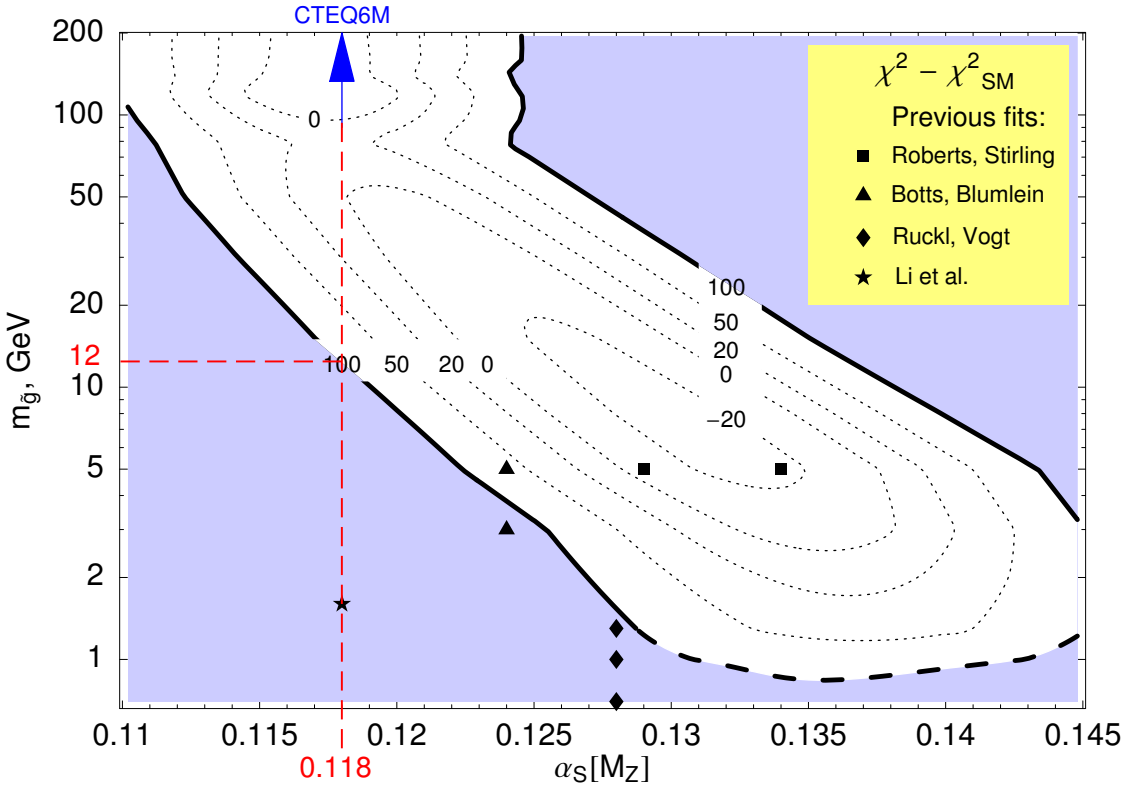
Phenomenology

Gluino Mass Limits from a Parton Density Analysis

E. L. Berger, P. Nadolsky, F. Olness, and J. Pumplin

[hep-ph/0406143], submitted to Phys Rev D

- Devise parton distributions for protons in which a gluino $\widetilde{g}$ is included along with SM quarks, antiquarks, and gluons.
- Obtain $\widetilde{g}$ density from gluon splitting for $Q > m_{\tilde{g}}$. NLO QCD evolution of parton densities.
- Excellent NLO QCD fit to the full set of hadron scattering data used in the CTEQ6 global analysis (1811 points). Tevatron jet data at large E_T included. Vary $m_{\tilde{g}}$ and $\alpha_s(M_Z)$. Contour plot of allowed values $\Delta\chi^2 < 100$:



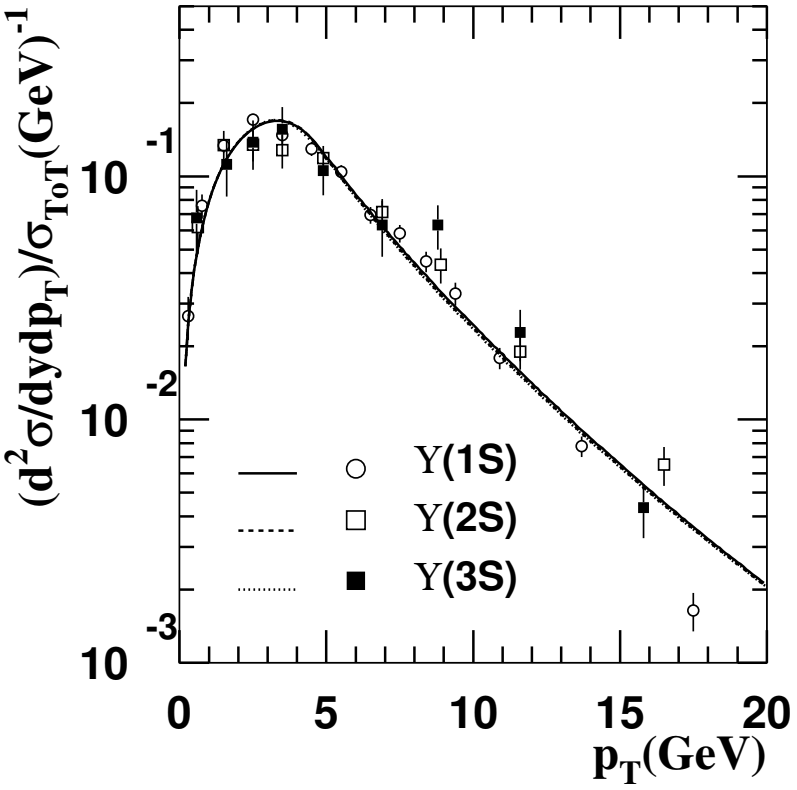
- Use full CTEQ6 error analysis approach to determine $m_{\tilde{g}} > 12$ GeV for SM world-average $\alpha_s(M_Z) = 0.118$, with smaller values of $m_{\tilde{g}}$ allowed for larger $\alpha_s(M_Z)$.

Transverse Momentum Distribution for Υ Production

E. L. Berger, J. W. Qiu, and Y. Wang

[hep-ph/0404158], submitted to Phys Rev D

- Fixed order QCD perturbation theory for $p\bar{p} \to \Upsilon X$ is divergent at small p_T; $\sigma \propto (1/p_T^2) \ln^2(m_\Upsilon^2/p_T^2)$.
- Develop and justify the validity of all-orders in α_s resummation of large logs from multiple soft gluon radiation to compute the distribution at small $p_T < M_\Upsilon$.
- Demonstrate that the p_T distribution at small p_T is dominated by the region of small impact parameter, and that the distribution may be computed reliably at small p_T in resummed perturbation theory.



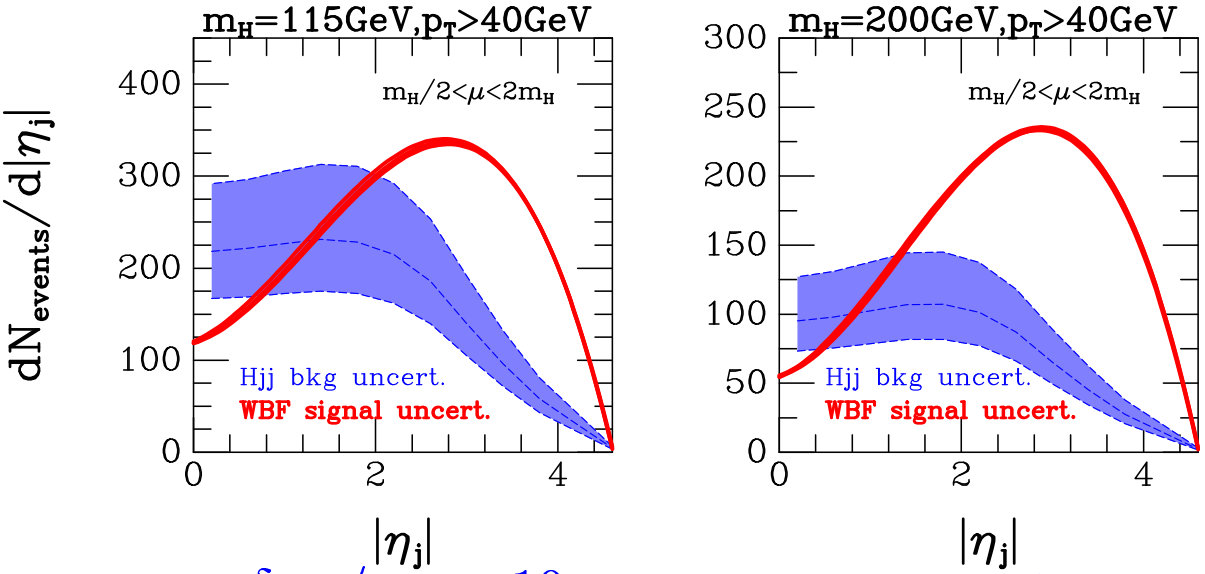
- Excellent agreement with 2002 CDF data over the full range of p_T; awaiting run-II data.

Higgs Boson Plus 2 Jet Production: WBF Signal at NLO and QCD Backgrounds

E. L. Berger and J. Campbell

[hep-ph/0403194], Phys Rev D, in press

- Motivation: after discovery of the Higgs boson, the goal becomes the measurement of its couplings. How well can this job be done in the weak boson fusion (WBF) sample?
- Independent QCD calculation of $H + 2$ jet processes
  - to gauge the effectiveness of cuts used to select the WBF signal, and
  - to evaluate the accuracy with which couplings g_H can be determined in experiments at the CERN LHC.
- As a function of the rapidity of a tagging jet, the figures show the WBF signal and the QCD $H + 2$ jet backgrounds, along with estimated uncertainties.



- Estimate $\delta g_H / g_H \sim 10\%$ should be possible after 200 fb^{-1}. Les Houches 2003 estimates of expected uncertainties are too optimistic ($\sim \times 2$).

Associated Production of a Top Quark and a Charged Higgs Boson tH^+

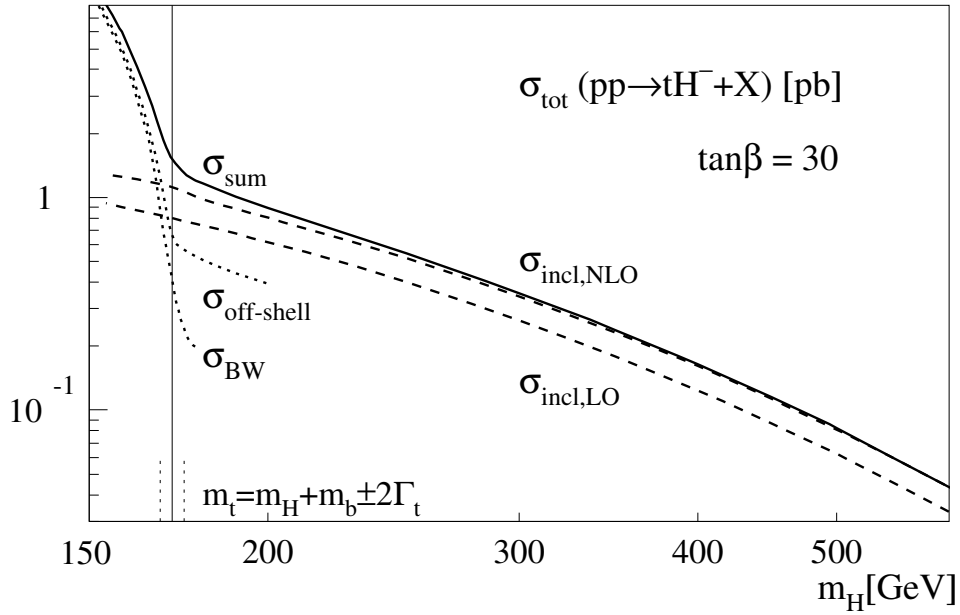
E. L. Berger, T. Han, J. Jiang, and T. Plehn

[hep-ph/0312286], submitted to Phys Rev D

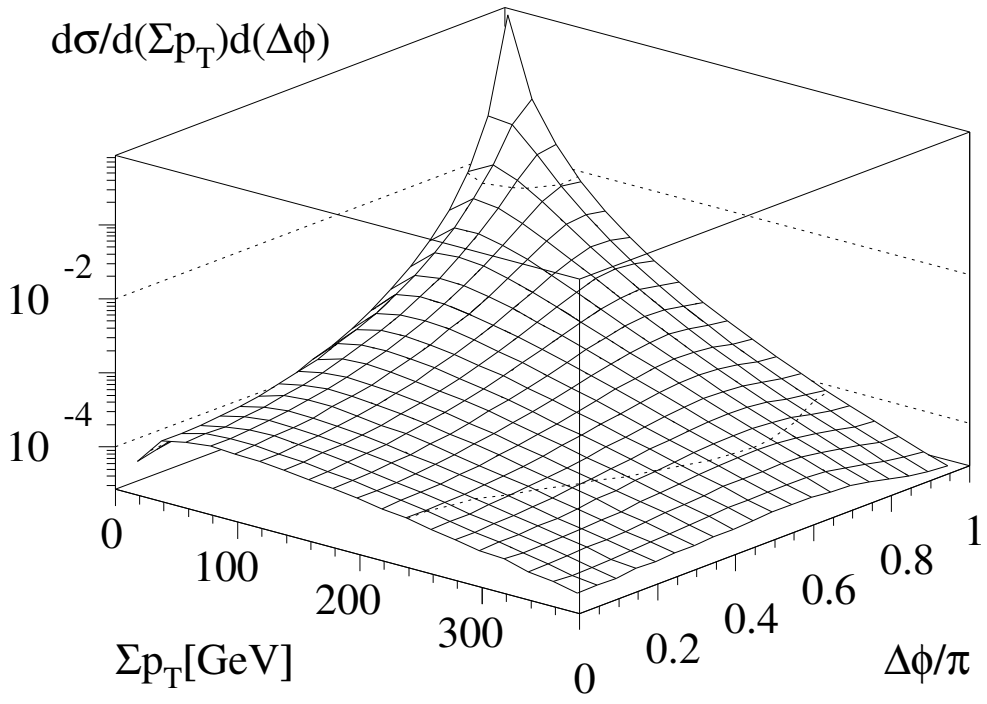
- Motivation: identification of a charged Higgs boson $H^\pm$ would provide evidence for a Higgs sector beyond the SM, meaning at least two Higgs doublets and, possibly, a supersymmetric Higgs sector.
- Compute the NLO inclusive and differential cross sections for $pp \to tH^- X$ at Tevatron and LHC energies in QCD and SUSY-QCD.
- For $m_H < m_{\rm top}$, include $t\bar{t}$ pair production, with $t \to bH^+$.
- All results are fully differential, permitting selections on the momenta of both the top quark and the charged Higgs boson, plus the study of correlations between final state particles. The two-cutoff phase-space slicing method is used to deal with the usual soft and collinear singularities.

tH^+ Associated Production, continued

- Total cross section at the LHC vs m_H. NLO result is the dashed upper curve. Also shown is the cross section for $pp \to t\bar{t}^*; \bar{t}^* \to \bar{b}H^-$ (at small m_H).



- Correlation between $\Sigma p_T = (\vec{p_t} + \vec{p_H})_T$ and $\Delta\phi = |\phi_t - \phi_H|$; $m_H = 250$ GeV.

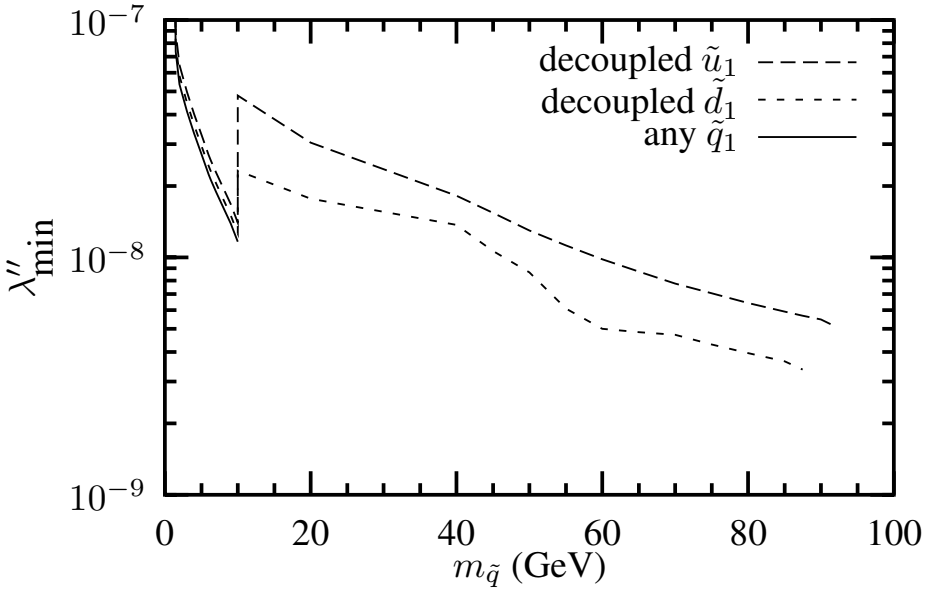


Lower limits on R-parity-violating couplings in SUSY models with light squarks

E. L. Berger and Z. Sullivan

[hep-ph/0310001], Phys. Rev. Lett **92**, 201801 (2004)

- If R parity (R_p) is conserved, SUSY particles are produced in pairs, each of which decays to a final state that includes a stable lightest SUSY particle (LSP).
- If R_p is not conserved, SUSY particles may decay into SM particles; missing energy signatures may be lost; and SUSY may not provide a dark matter candidate.
- Interpreted the results of (negative) LEP searches for stable strongly interacting massive particles to place absolute lower limits on R_p-violating couplings:
  λ'' or $\lambda' > 10^{-8}$–10^{-7}, if $m_{\tilde{q}} < 100$ GeV.



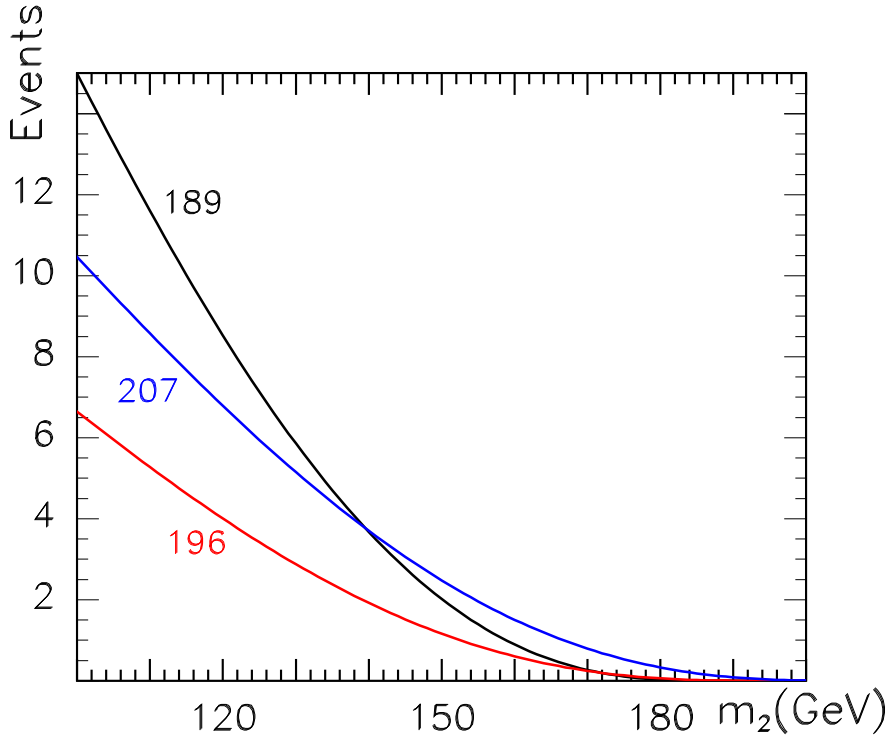
- If R_p violation is this large, $\tilde{\chi}^0$ cannot explain dark matter.

Squark Mixing in e^+e^- Reactions

E. L. Berger, J. Lee, and T. Tait

[hep-ph/0306110], Phys Rev D **69**, 055003 (2004)

- For each squark flavor, there are two mass eigenstates, one light $\widetilde{q}_1$ and one heavy $\widetilde{q}_2$. The mixing that results in these two states is characterized by a mixing angle θ_q.
- Examine prospects for direct measurement of the top-squark and bottom-squark mixing angles in associated production $e^+e^- \to \widetilde{q}_1\widetilde{q}_2^*$.
- Compute cross sections for LEP-II and a Linear Collider.
- In the context of a light bottom squark scenario, show that existing data from LEP-II should show definitive evidence for the heavier bottom squark if $m_2 < 120$ GeV.
- Numbers of events in $e^+e^- \to \widetilde{b}_1\widetilde{b}_2^*$ vs m_2 for 3 LEP-II energies.



Polarization of J/ψ's at the Tevatron

- INTRODUCTION:

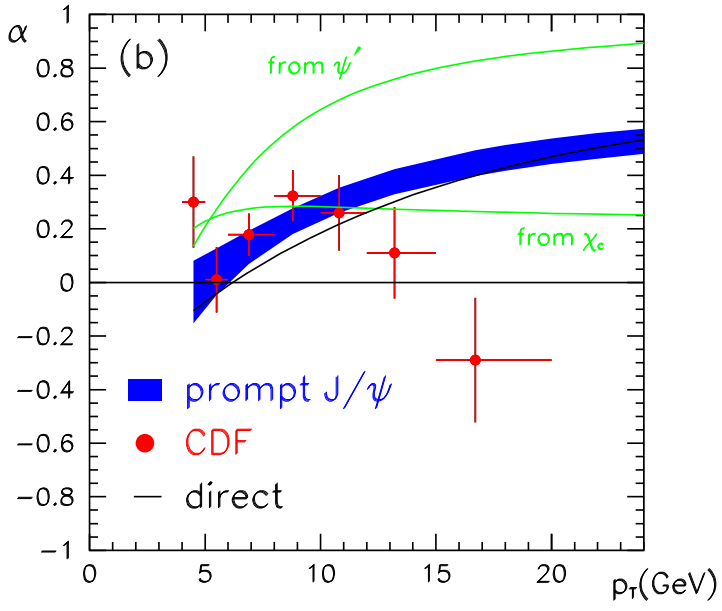
- Gluon fragmentation into J/ψ is the dominant production mechanism at large p_T at the Tevatron.

- The gluon produces a $Q\overline{Q}$ pair that evolves nonperturbatively into the J/ψ.

- Nonrelativistic QCD (NRQCD) velocity-scaling rules predict that, in the evolution, the spin-non-flip interactions dominate over spin-flip interactions.
  - Corrections of order $v^2 \approx= 0.3$.

- Hence, the J/ψ is predicted to take on most of the transverse polarization of the gluon (P. Cho, M. Wise).

- The CDF data for the polarization parameter α lie significantly below the prediction at the largest p_T:



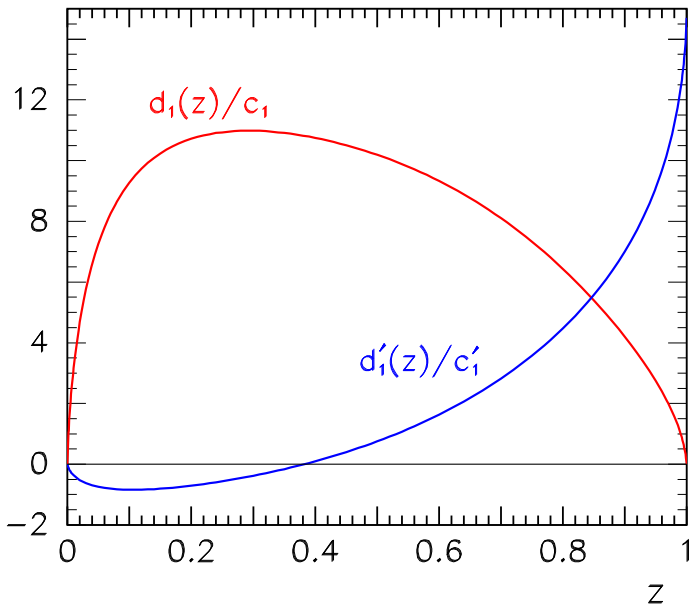
Relativistic Corrections to Gluon Fragmentation into J/ψ

G. Bodwin and J. Lee

Phys. Rev. D **69**, 054003 (2004)

- MOTIVATION:
- Relativistic corrections to quarkonium decay processes are known to be large.
- Investigate whether large relativistic corrections can affect the predicted net transverse polarization of J/ψ's at the Tevatron.
- COMPUTATION:
- Compute in perturbation theory the short-distance coefficients for the fragmentation process.
- Estimate the nonperturbative NRQCD matrix elements from the the quarkonium binding energy (Gremm-Kapustin relation).

- Computation of the fragmentation in the color-singlet channel is involved.
  - Three-body phase space: use changes of variables to carry out two of four nontrivial integrations analytically.
  - Very large expressions manipulated using Mathematica, Reduce.
- RESULTS:
- Confirmed previous calculations of leading-order fragmentation short-distance coefficients (E. Braaten, T. C. Yuan, J. Lee).
- Computed fragmentation short-distance coefficients in order v^2:



The color-singlet short-distance coefficients $d_1(z)$ and $d_1'(z)$. The scaling factors in this figure are $c_1 = 10^{-4} \times \alpha_s^3/m^3$ and $c_1' = 10^{-3} \times \alpha_s^3/m^3$.

- Correction to color-singlet short-distance coefficient: $2.45v^2 \approx 70\%$ for J/ψ.
- Correction to color-octet short-distance coefficient: $-1.8v^2 \approx -50\%$ for J/ψ.
- The change in the color-singlet short-distance coefficient reduces the predicted α by about 10% at the largest p_T.
  - Still disagrees with the CDF data point at the highest p_T.
- The change in the color-octet short-distance coefficient affects the size of the color-octet matrix element in the fit to the Tevatron data.
  - No change in the predicted production rate at the Tevatron.
  - Will eventually be important in testing universality of matrix elements from process to process.

Lattice Computation of Spin Correlations in NRQCD Color-Octet Matrix Elements

G. Bodwin, J. Lee, D. Sinclair

- MOTIVATION:
- Would like to test the validity of the NRQCD velocity-scaling rules for the J/ψ production matrix elements.
- It is not known how to formulate the computation of production matrix elements on a Euclidean lattice.
- Instead, test the velocity-scaling rules on the corresponding decay matrix elements.
- Two versions of the required lattice code have been written independently and now agree in their numerical output.
- Order v^4 and order-a^2 and corrections to the NRQCD lattice action have been incorporated.

- PRELIMINARY RESULTS ($\frac{\text{color-octet m.e.}}{{}^3S_1 \text{ color-singlet m.e.}}$)

Υ at $\beta = 5.7$:

Spin Transition	Lattice	v-Scaling
triplet $\rightarrow$ singlet	5.5×10^{-3}	$v^3/(2N_c) \approx 5.3 \times 10^{-3}$
singlet $\rightarrow$ triplet	1.8×10^{-3}	$v^3/(2N_c) \approx 5.3 \times 10^{-3}$
singlet $\rightarrow$ singlet	7×10^{-5}	$v^4/(2N_c) \approx 1.7 \times 10^{-3}$
triplet $\rightarrow$ triplet	8×10^{-5}	$v^4/(2N_c) \approx 1.7 \times 10^{-3}$
triplet up $\rightarrow$ triplet up	8×10^{-5}	$v^4/(2N_c) \approx 1.7 \times 10^{-3}$
triplet up $\rightarrow$ triplet long.	noise	$v^6/(2N_c) \approx 1.7 \times 10^{-4}$
triplet up $\rightarrow$ triplet down	3.1×10^{-6}	$v^6/(2N_c) \approx 1.7 \times 10^{-4}$

J/ψ at $\beta = 5.7$:

Spin Transition	Lattice	v-Scaling
triplet $\rightarrow$ singlet	3.8×10^{-2}	$v^3/(2N_c) \approx 2.7 \times 10^{-2}$
singlet $\rightarrow$ triplet	1.8×10^{-2}	$v^3/(2N_c) \approx 2.7 \times 10^{-2}$
singlet $\rightarrow$ singlet	3.9×10^{-4}	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
triplet $\rightarrow$ triplet	9×10^{-4}	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
triplet up $\rightarrow$ triplet up	5×10^{-4}	$v^4/(2N_c) \approx 1.5 \times 10^{-2}$
triplet up $\rightarrow$ triplet long.	1.0×10^{-4}	$v^6/(2N_c) \approx 4.5 \times 10^{-3}$
triplet up $\rightarrow$ triplet down	3×10^{-4}	$v^6/(2N_c) \approx 4.5 \times 10^{-3}$

- $v^2 \approx 0.3$ for J/ψ; $v^2 \approx 0.1$ for Υ.
- Hierarchy of v-scaling preserved, but suggests a smaller expansion parameter ($1/\pi$ for each loop?).
- The triplet $\rightarrow$ singlet transition rate is large.
  - η_c production rate at the Tevatron may be comparable to the J/ψ production rate.
- The transverse $\rightarrow$ longitudinal transition is small compared with the transverse $\rightarrow$ transverse transition.
  - The prediction of large transverse polarization at large p_T at the Tevatron is supported.
- At $\beta = 5.6$, the lattice momentum cutoff is $\pi/a \approx 4.1$ GeV $> m_c$.
  - Spurious power-divergent contributions may be contaminating the J/ψ matrix elements.
  - Work on controlling them is in progress.

NRQCD Factorization vs. the Color-Evaporation Model

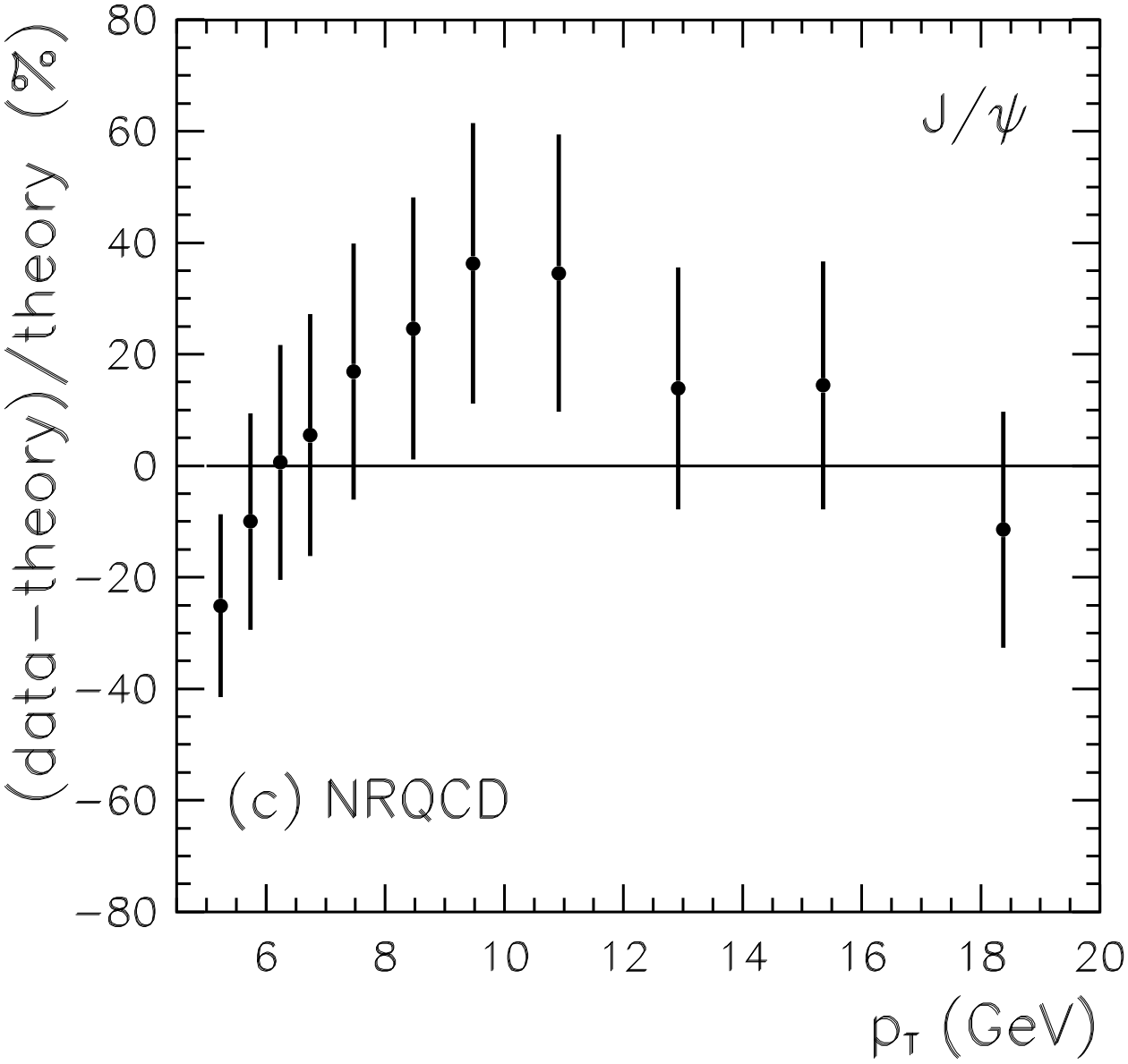
G. Bodwin, E. Braaten, and J. Lee

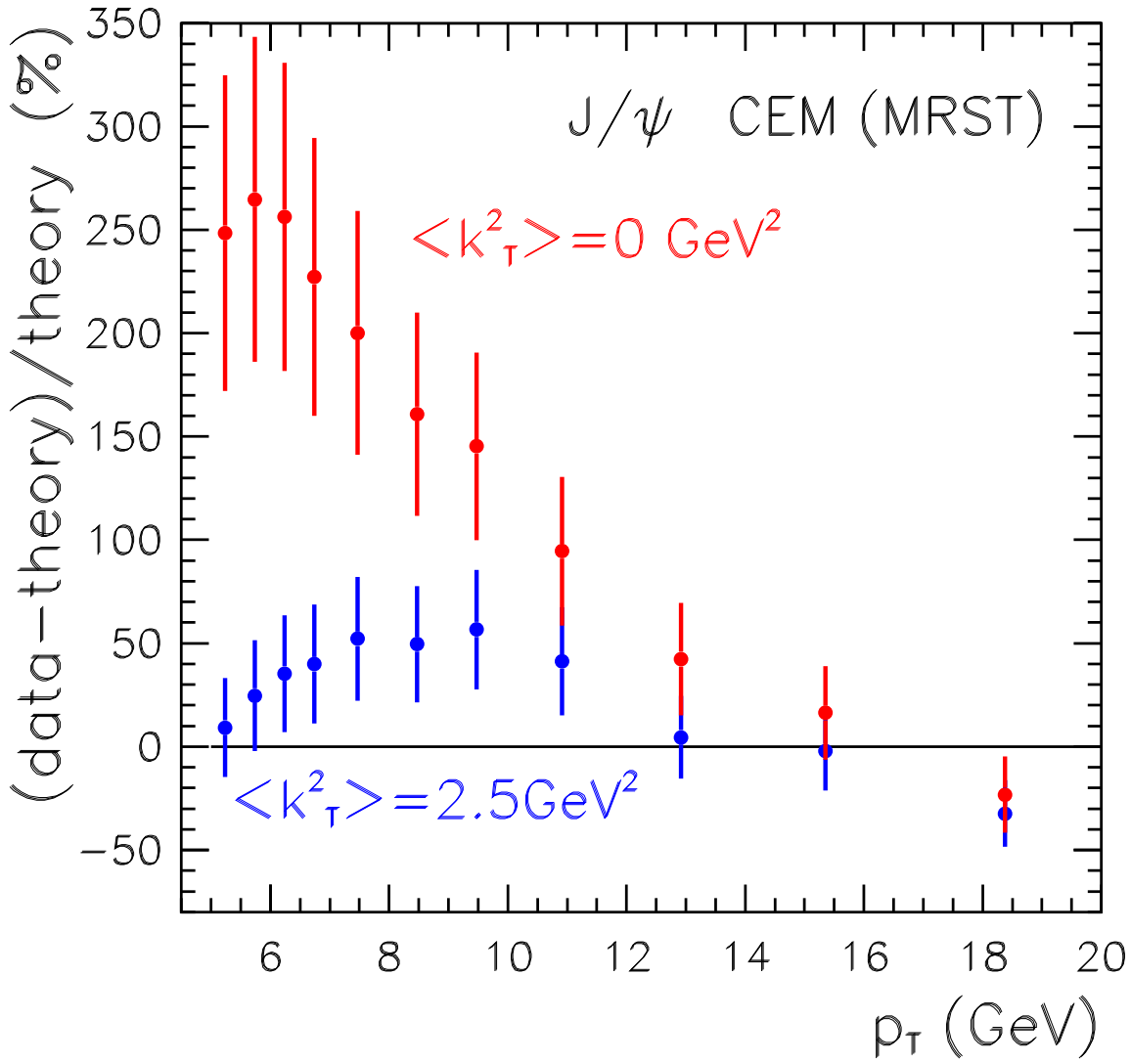
- The color-evaporation model (CEM) is the only viable competitor to the NRQCD factorization approach for describing quarkonium production.
- The CEM quarkonium production cross sections for $c\bar{c}$ below open charm threshold, summed over spin and color, times phenomenological constants.
- Can calculate the CEM cross sections using the perturbative NRQCD factorization expression for $c\bar{c}$ production.
- Leads to predictions for the relative sizes of the NRQCD matrix elements for compatibility with the CEM:

$$\langle \mathcal{O}_n^H \rangle = \frac{3(2j_n+1)}{2l_n+3} C_n k_{\rm max}^{2l_n} \langle \mathcal{O}_1^H ({}^1S_0) \rangle.$$

  $C_n = 1$ for color-singlet m.e.; $C_F = 4/3$ for color-octet m.e.
  $k_{\rm max} = \sqrt{m_D^2 - m_c^2}$.
- The CEM predictions satisfy v-scaling for the ratio of the most important matrix elements for J/ψ production, but not for χ_c production.
  They also give a color factor that disagrees with NRQCD for χ_c production.

- The numerical agreement of the CEM predictions with NRQCD matrix elements extracted from the Tevatron data is poor, especially for χ_c.
- Conclusion: The CEM and NRQCD predict very different proportions for the various $c\bar{c}$ spin, orbital-angular-momentum, and color channels in quarkonium production.
- Nevertheless, both the CEM and NRQCD fit the data reasonably well:





- However, the CEM prediction requires k_T smearing to fit the data, while the NRQCD prediction does not.
- Work is in progress on the effect of k_T smearing (multiple gluon emission) on the NRQCD predictions.

LATTICE QCD — D. K. Sinclair.

- Charmonium decay matrix-elements related to high-p_T charmonium production and polarization. (with G. T. Bodwin and J. Lee).
- The transition from hadronic-matter to a quark-gluon plasma at finite temperature and small densities and the search for the critical endpoint. (with J. B. Kogut).
- The transition from hadronic-matter to a quark-gluon plasma at finite temperature at zero quark mass. (with J. B. Kogut).
- The spectrum of lattice QCD at zero quark mass and tests of chiral extrapolation. (with J. B. Kogut).

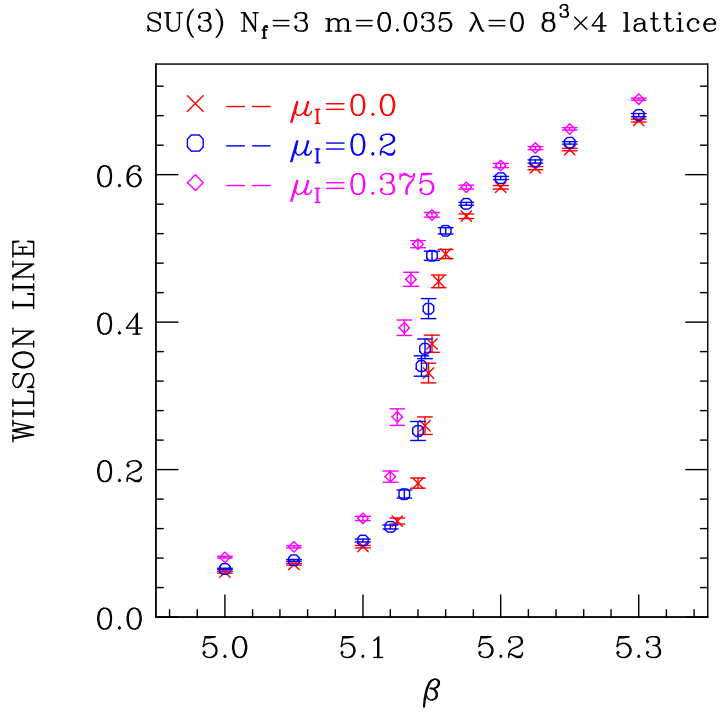
Comments

- QCD finite T transition relevant to early universe, high energy heavy-ion and possibly hadron collisions. Yields information on chiral symmetry breaking, confinement and QCD dynamics in general.
- Chiral extrapolation is a persistent source of poorly controlled errors in lattice QCD calculations.
- Computing is performed on IBM SP's at NERSC and NPACI, and Linux clusters at LCRC (Argonne) and NCSA.

Lattice QCD at finite T and μ_I

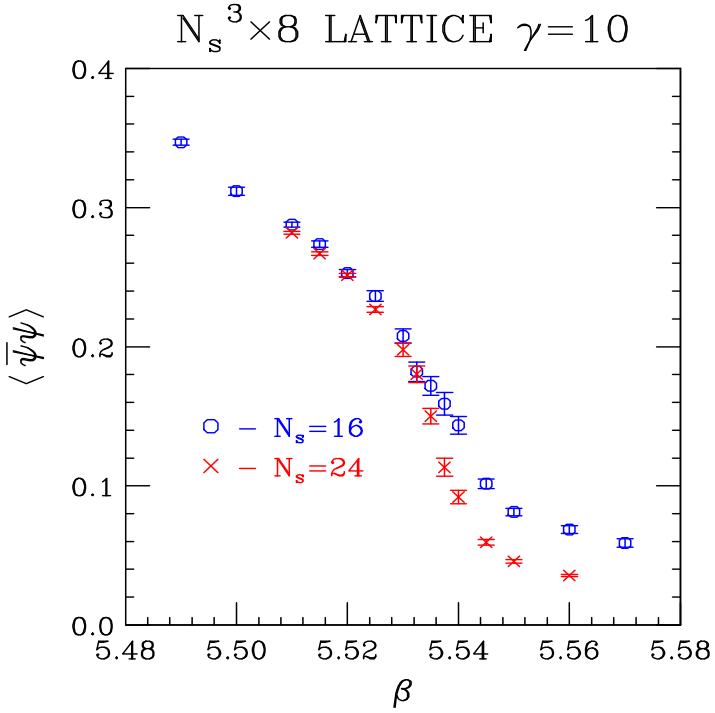
- QCD at finite quark-number chemical potential μ has a complex fermion determinant.
- Ignoring the phase we have QCD at finite isospin (I_3) chemical potential $\mu_I = 2\mu$, which can be simulated.
- For $N_f = 2, T_c$ decreases *slowly* with increasing μ These simulations are being extended to $N_f = 3$

- $N_f = 3$ simulations are in progress.



Lattice QCD with massless quarks at finite T

- The transition from hadronic matter to a quark-gluon plasma for 2 light quark flavours is a crossover for $m_q \neq 0$.
- It becomes a second-order chiral-symmetry-restoring transition at $m_q = 0$.
- Lattice QCD action improved to enable simulating at $m_q = 0$.
- An analysis of the behaviour of the chiral order parameter in the neighbourhood of this transition on $16^3 \times 8$ and $24^3 \times 8$ lattices ($\gamma = 3/\lambda^2$) has been performed.



Hadron spectrum in chiral limit under investigation

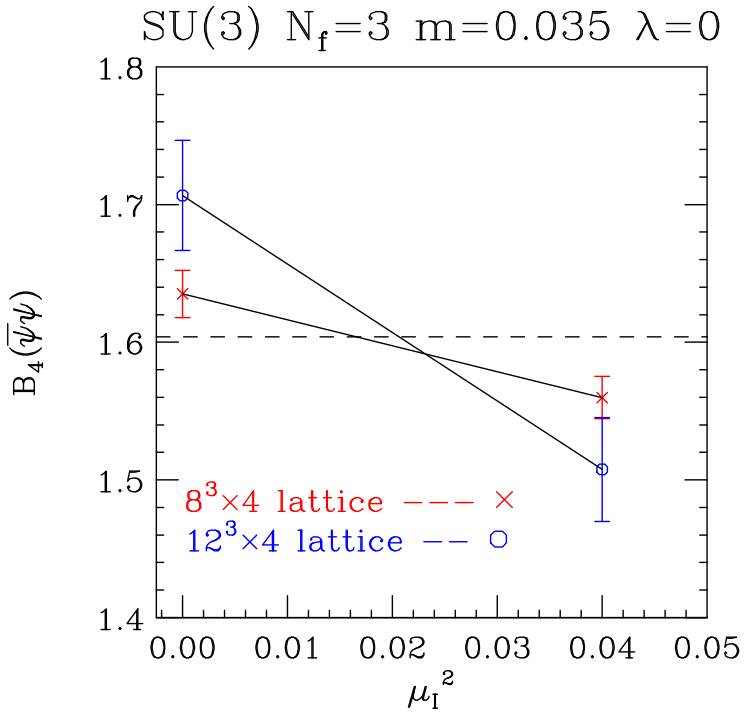
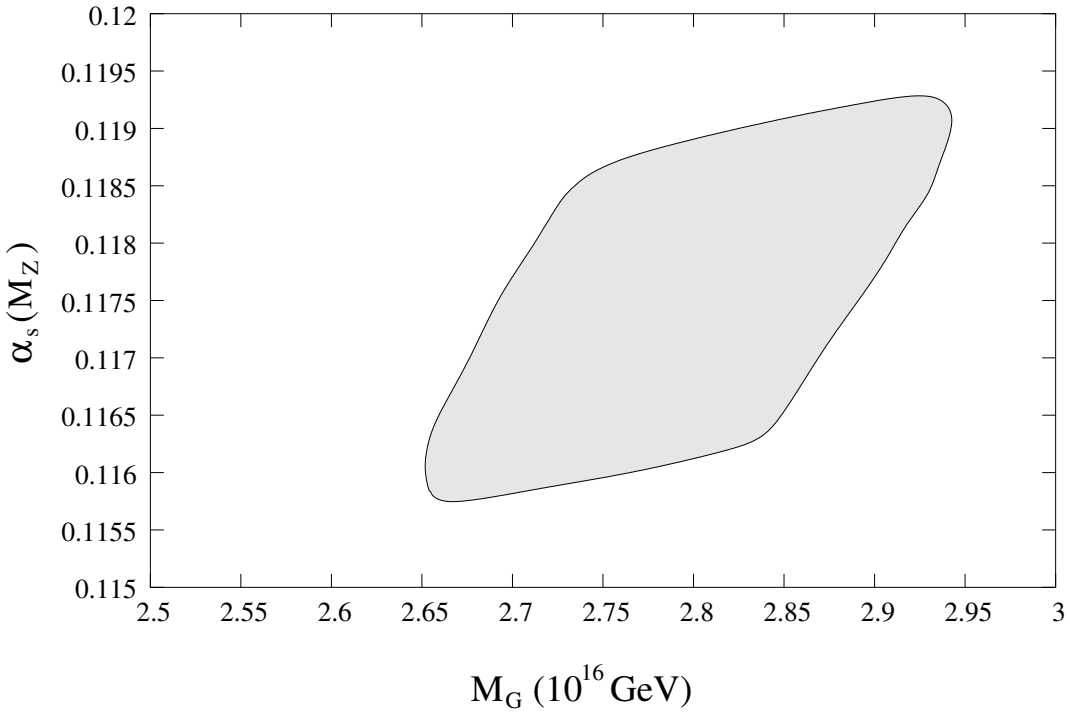


Figure 1: Binder cumulants for $m = 0.035$ as functions of μ_I. Dashed line is at the Ising value expected for the critical endpoint.

Precision Data, heavy Vector Quarks and Collider Phenomenology

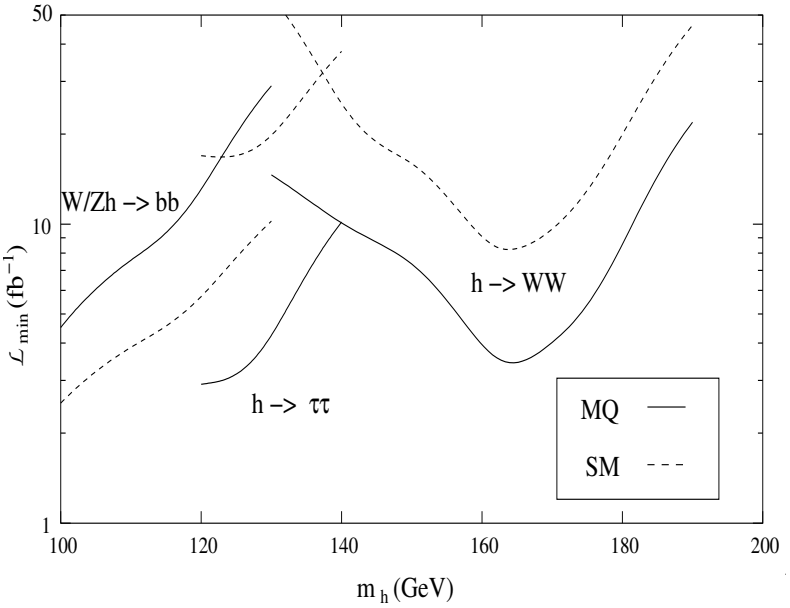
D. Morrissey and C.E.M. Wagner, Phys. Rev. D 69, 053001 (2004)

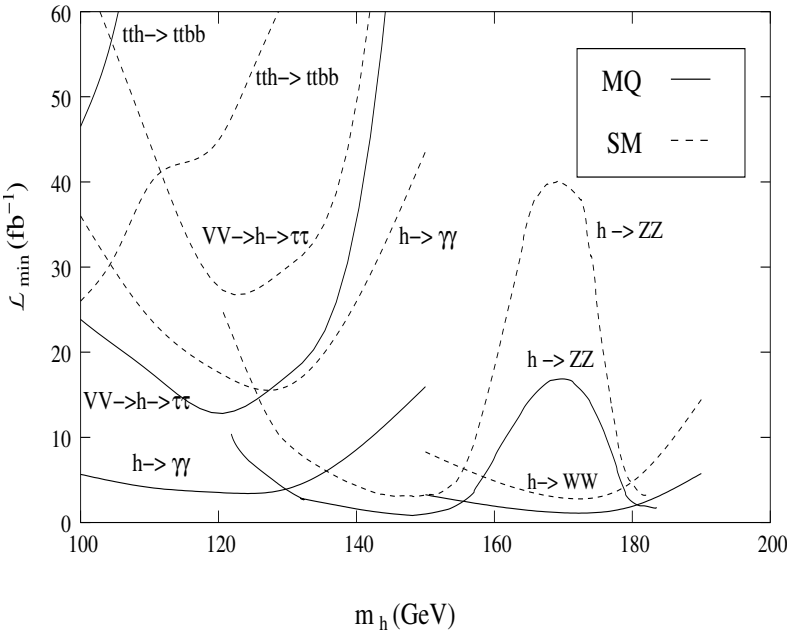
- Discrepancy between value of $\sin^2\theta_W$ obtained from lepton and bottom-quark asymmetries
- It may be arranged by the introduction of heavy vector $SU(2)$ doublet and singlet b-like quarks.
- Modification of Z-coupling due to mixing with b-quark. Masses of heavy top-like and bottom-like quarks smaller than 250 GeV and 300 GeV, respectively.
- They may be found at the Tevatron with 4 fb^{-1}.
- Improvement of Unification conditions



Heavy Quark Impact on Higgs Physics

- Extra heavy quarks enhance the Higgs coupling to gluons, and therefore the dominant Higgs production channel at hadron colliders.
- Branching ratio of decay into tau leptons also enhanced.



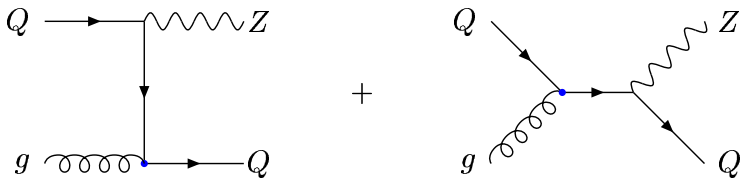


Associated Production of a Z Boson and a Heavy-Quark Jet

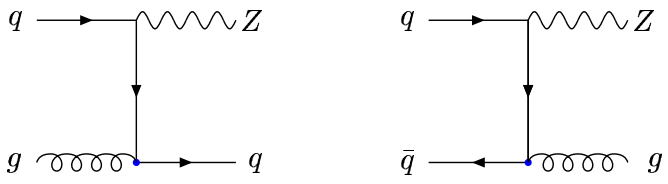
J. Campbell, R. K. Ellis, F. Maltoni and S. Willenbrock

[hep-ph/0312024], accepted for publication in Phys. Rev. D

- NLO calculation using heavy-quarks in the initial state.



- Background at the Tevatron and LHC to $gb \to hb$.
- At the LHC, measures heavy-quark distribution functions.
  - no direct measurement at present
  - needed for $b\bar{b} \to h$, $gb \to hb$, $gb \to H^- t$, single top
- Including detector efficiency, there are approximately 80 $Z(\to \ell^+\ell^-)b$ events for every $100\mathrm{pb}^{-1}$ at the Tevatron.
- Can reduce systematic errors by considering the ratio of tagged $Z + b$ to untagged $Z + \mathrm{jet}$.



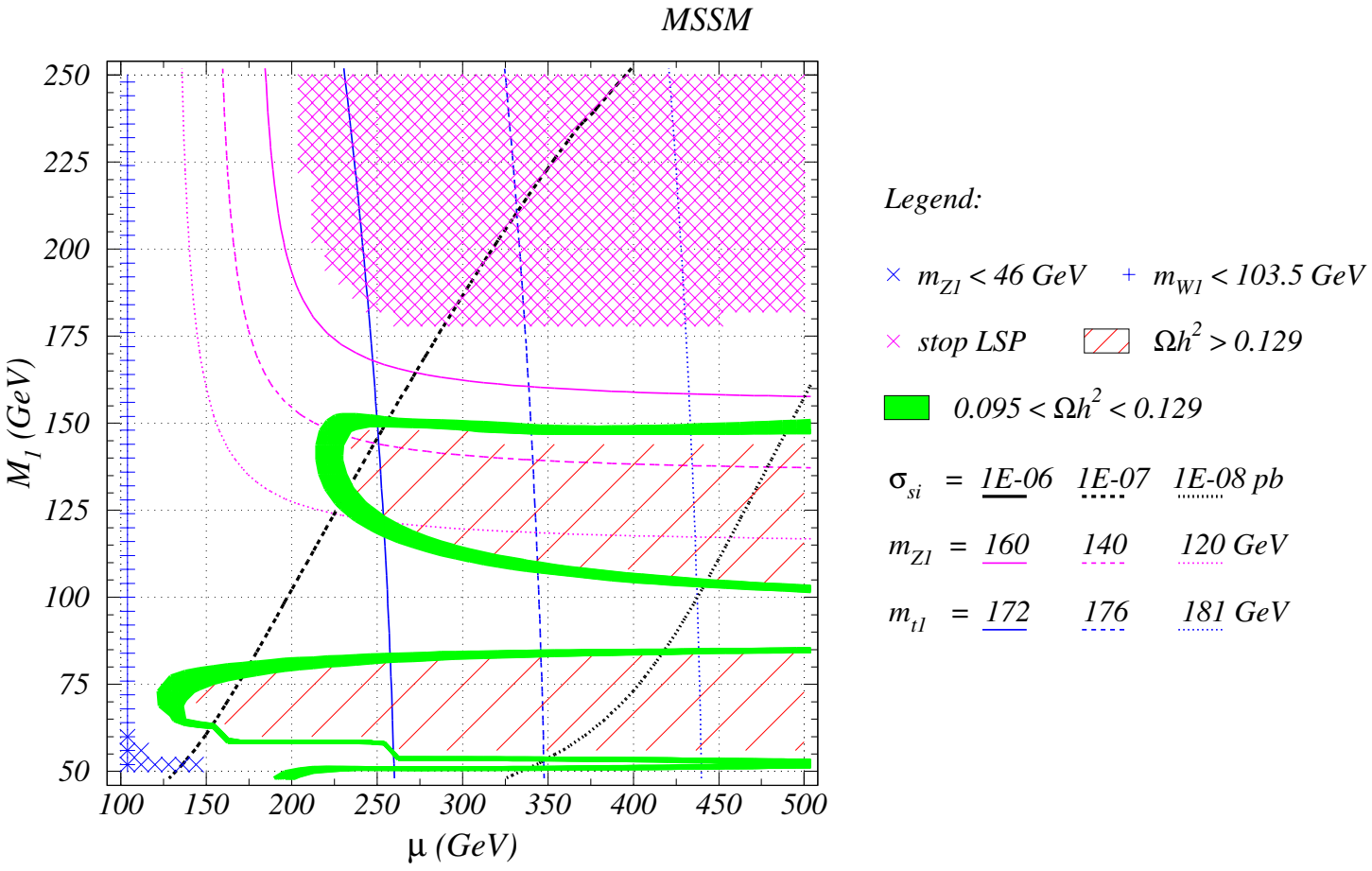
  - theory prediction for ratio is 0.02 ± 0.04
  - DØ Run II measurement is 0.024 ± 0.007

Dark Matter and Electroweak Baryogenesis

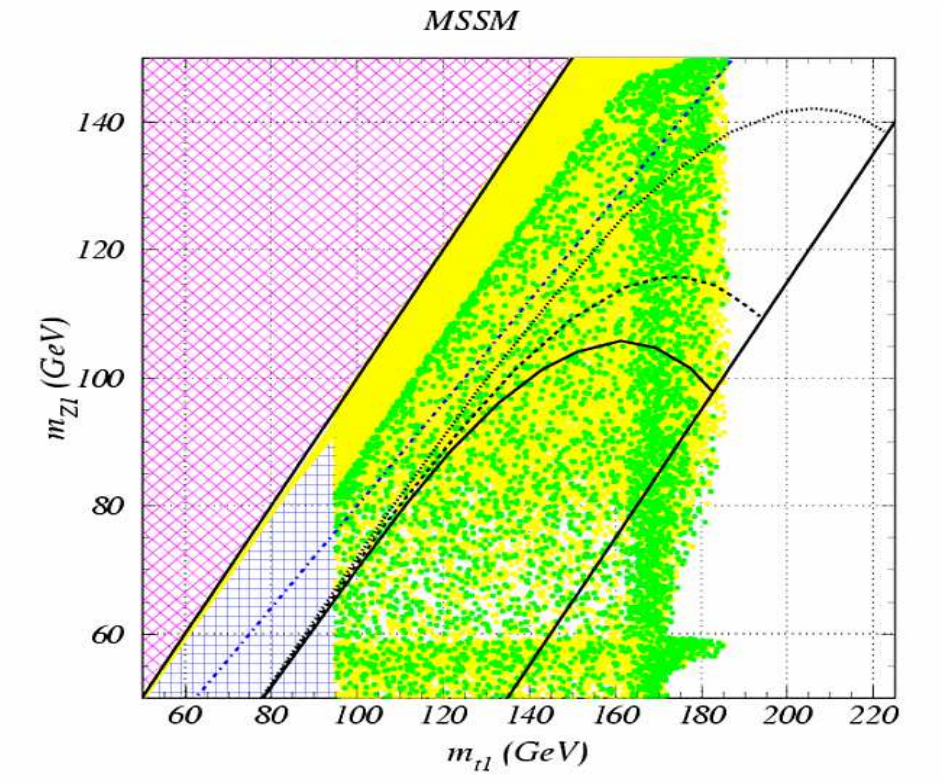
C. Balázs, M. Carena and C. W.,

Phys.Rev.D70:015007,2004.

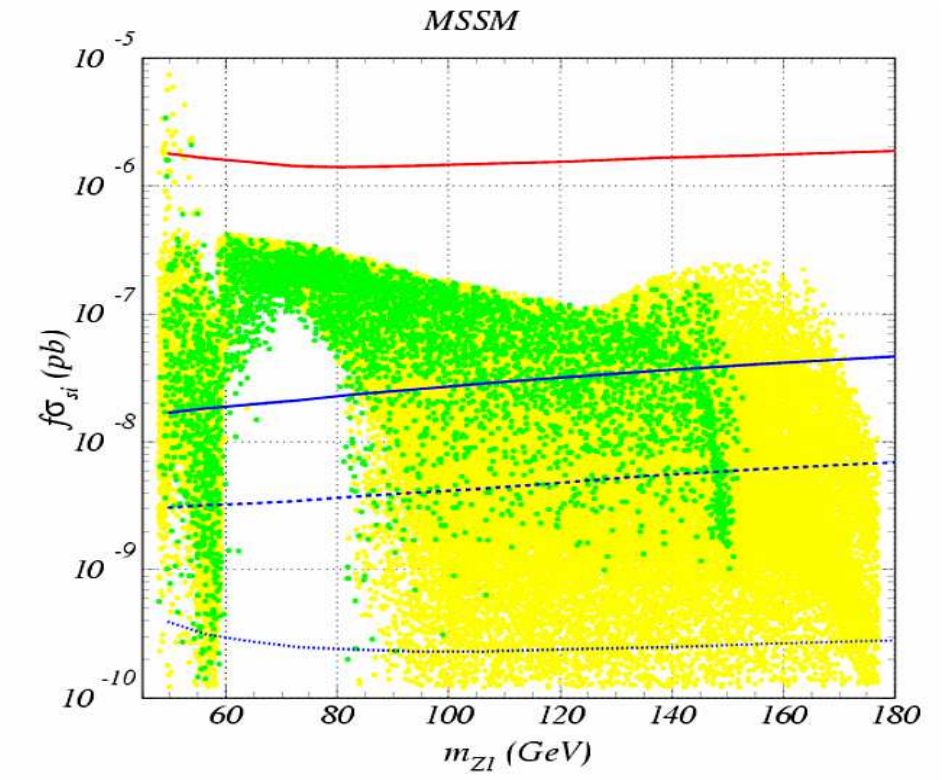
- Explaining baryon asymmetry and dark matter simultaneously.
- MSSM provides new CP-violating sources and an excellent dark matter candidate.
- Computation of neutralino relic density with light stops and Higgses.



- Scenario is testable at the Tevatron ...



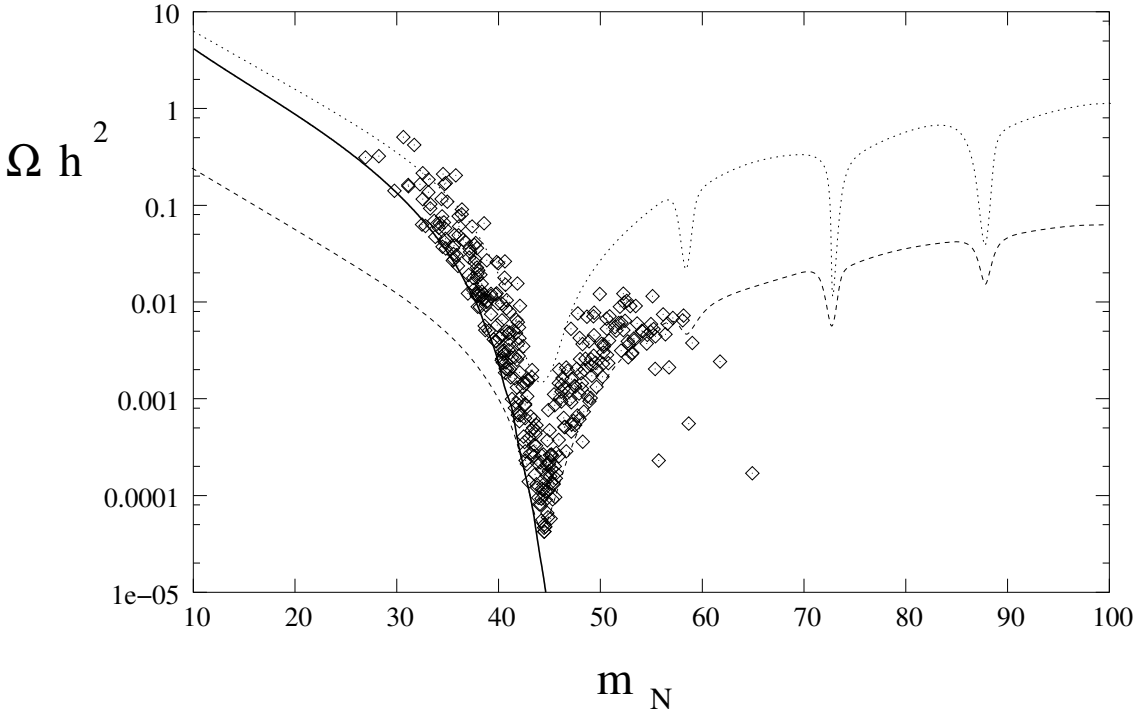
- ... and in direct dark matter detection experiments.



Dark Matter and Electroweak Baryogenesis in the nMSSM

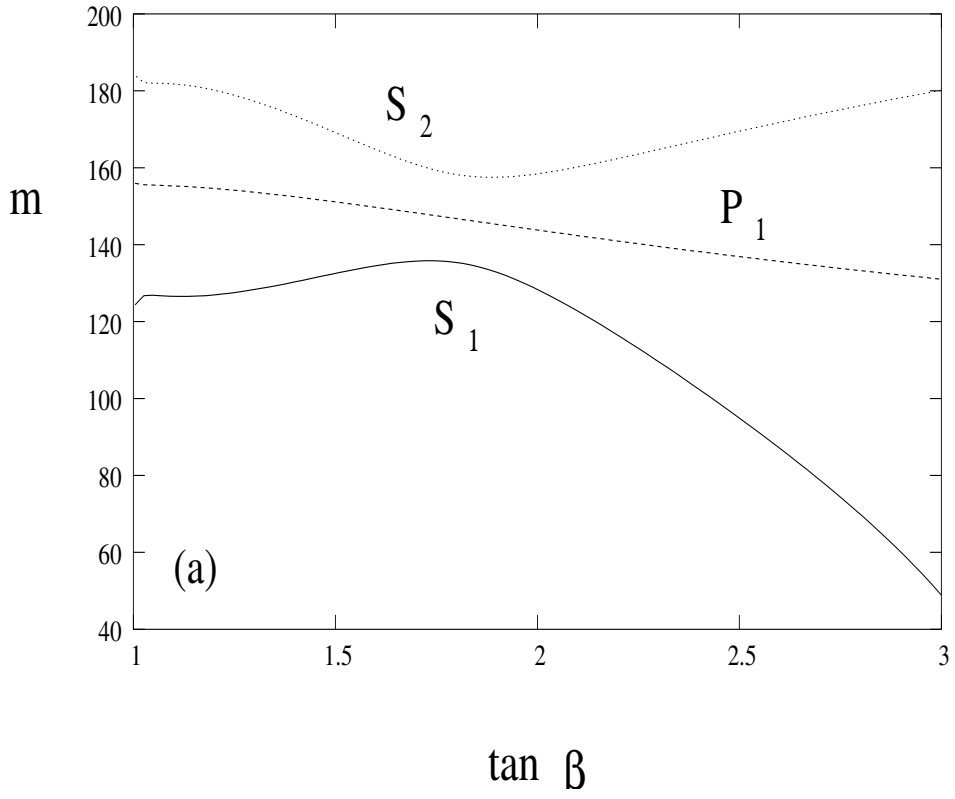
A. Menon, D. Morrissey and C. W., Phys.Rev.D70:035005,2004.

- Minimal Extension of the MSSM, with an extra singlet superfield
- Gives a natural explantion of size of μ parameter, without inducinig dangerous domain walls
- First order phase transition induced already at tree level (no neeed of light stops)
- Same CP-violating sources as in the MSSM
- Light Higgsino-Singlino state gives an excellent dark matter description



Higgs Physics

- Large values of charged Higgs mass
- Singlet CP-even and CP-odd component lighter than 250 GeV, due to requirement of phase transition strength



- Lightest Higgs decays mostly invisibly
- Discovery difficult at Tevatron. At the LHC, feasible in weak boson fusion channel

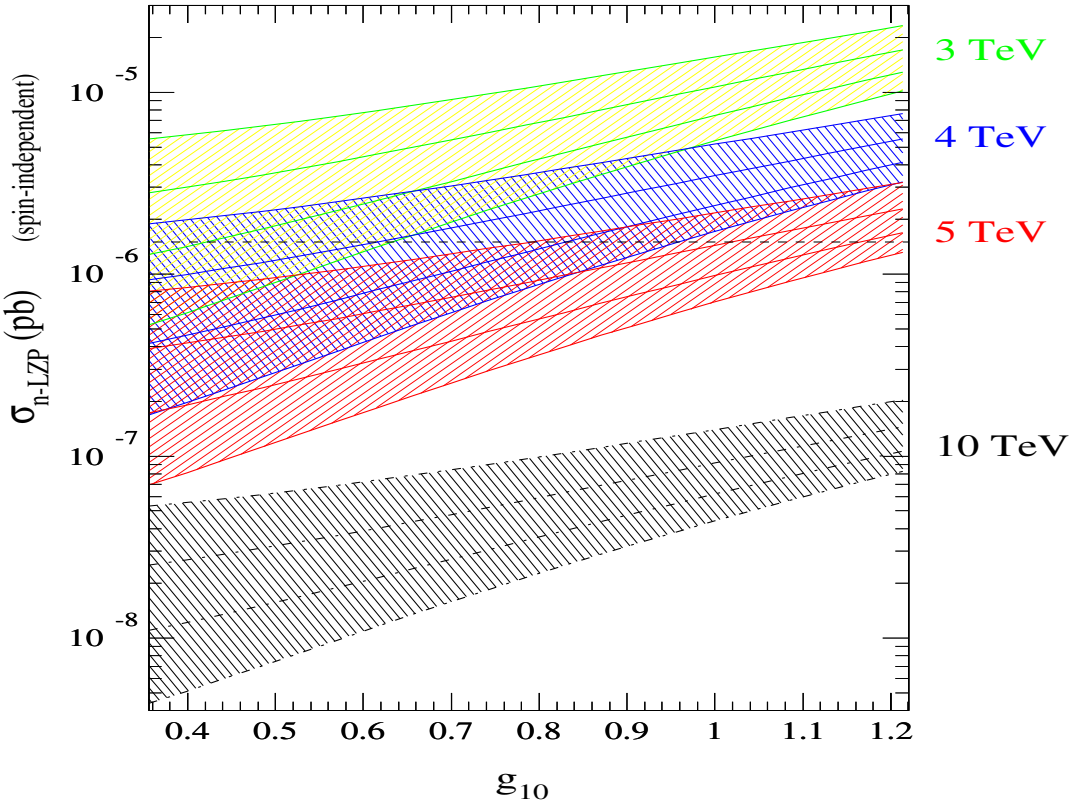
$$\mathcal{L}_{95\%} \simeq \frac{1.2\ \mathrm{fb}^{-1}}{\eta^2}, \qquad \mathcal{L}_{5\sigma} \simeq \frac{8.0\ \mathrm{fb}^{-1}}{\eta^2}, \quad (1)$$

Warped GUT: Towards a realistic model

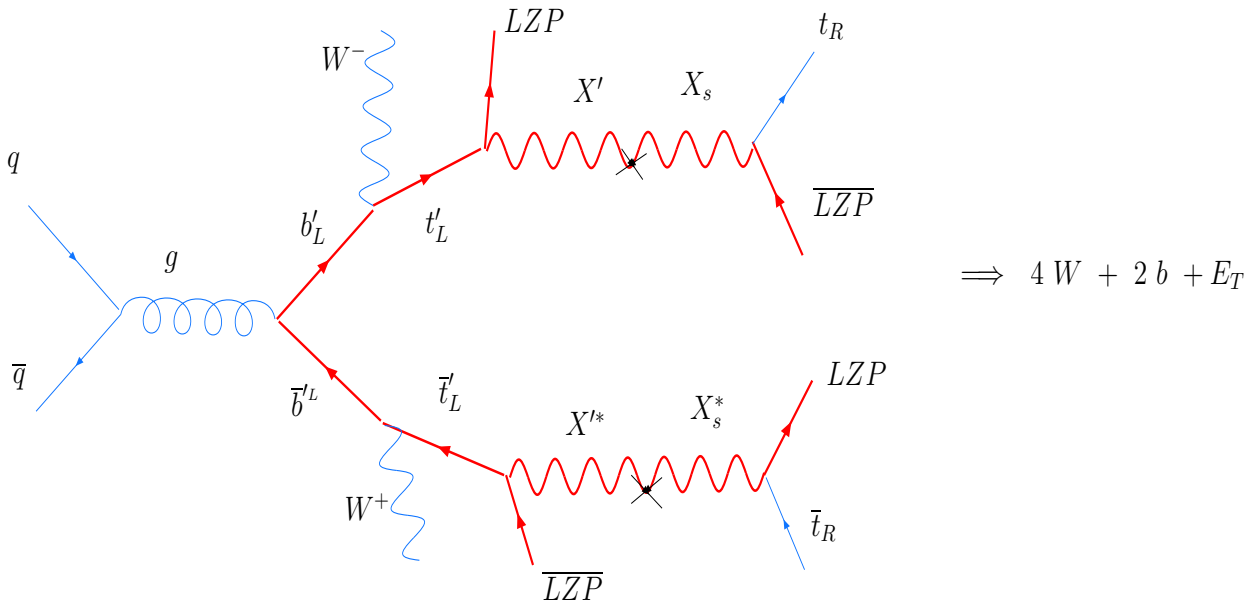
Géraldine Servant

- AdS_5 geometry generates the exponential hierarchy between M_{Pl} and M_{EW} (no need for SUSY).
- All SM fields propagate in a slice of AdS_5 except the Higgs which is localized at one boundary.
- Geometrical solution to the hierarchical flavor structure of SM fermion masses.
- Unification of gauge couplings at high scale (usual M_{GUT}) despite the infinite tower of Kaluza-Klein states.
- We addressed the pb of baryon number violation and showed that a gauged baryon number symmetry can be consistent with higher dimensional GUT.
- Like in SUSY, resolving the proton stability problem leads to a stable particle: The lightest Kaluza-Klein excitation of the right-handed neutrino in $SO(10)$, which is no more sterile but interacts with TeV mass KK excitations of $SO(10)$ gauge bosons. Thus it behaves as a typical WIMP and is an ideal dark matter (DM) candidate.
- Model will soon be tested at DM direct detection expts:

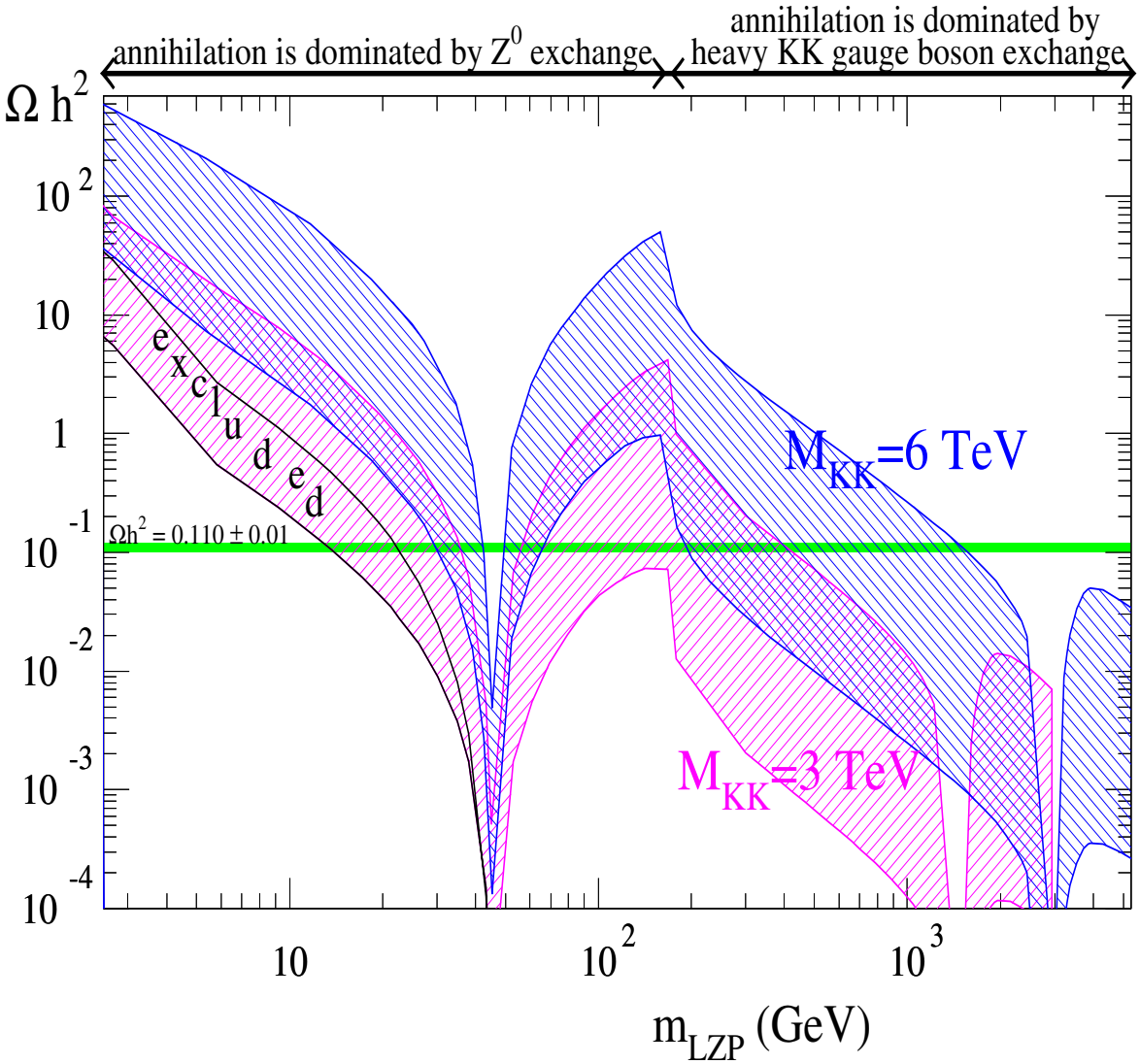
Predictions for elastic scattering expts:



We predict other light KK states with high potential for discovery at colliders:



Relic density predictions



C Zachos Phys Lett **B570** (2003) 82-88

MEMBRANES & CONSISTENT QUANTIZATION OF NAMBU DYNAMICS

T Curtright & C Zachos [hep-th/0312048]

BRANES, STRINGS, & ODD QUANTUM NAMBU BRACKETS

- In contrast to strings, brane quantization is an open problem.

Partial gauge fixing of covariant branes yields topological open membranes (analogous to WZW interactions):

$$S = \int (z1 \wedge dz2 \wedge dz3 \wedge ...dz^p + I_1 dt \wedge dI_2 \wedge ...dI_{p-1}),$$

(p-2)-branes undulating in p-dim spacetimes.

Their classical eqns of motion amount to a Jacobian,

$$\frac{dz^l}{dt} = \epsilon^{lij...k} \partial_i I_1 \partial_j I_2 ... \partial_k I_{p-1} = \frac{\partial(z^l, I_1, I_2, ..., I_{p-1})}{\partial(z1, z2, ..., z^p)}.$$

So, classically, instead of Hamilton's eqns, they are

$$\dot{z}^l = \{z^l, I_1, I_2, ..., I_{p-1}\},$$

the celebrated Nambu Bracket, with p-1 "Hamiltonians" I_i.

A p-even Nambu Bracket is the Pfaffian of the matrix of Poisson Brackets, $\{I_i, I_j\}$, and so can always be resolved in terms of strings of them!

- But what are the corresponding quantum equations?

A 30 year old conundrum: reputed inconsistencies of Quantum Nambu Brackets.

- CZ & TC proved that Quantization is consistent for even brackets— in fact, Maximally Superintegrable Systems in phase space are automatically quantized this way (multi-oscillator systems, hyperspherical/chiral models, Hydrogen atom, ...), given sound understanding of their NB structure.

- Odd QNBs do have genuine problems, essentially because they lack the correct classical limit to odd classical NBs; so they must be redefined!

• Even QNBs are associative, and do satisfy the proper antisymmetric Generalized Jacobi Identity, but not a misperceived “Fundamental” Identity, adopted by mathematicians virtually without exception.
That one reflects a derivation property cleverly bypassed by all known solved systems through entwinement of operators. A fork in the road: Nature chooses associativity over this derivation property.

$\rightsquigarrow$ Odd NBs are quantized by embedding them in an even space with an extra dynamical variable, promoting them to even ones, and then quantizing those, without problems.

• Systematic success in a broad class of models, including non-hamiltonian systems.

C Zachos, Mod Phys Lett A19 (2004) 1483 [hep-th/0402127]

COMMENT ON "Noncommutativity as a Possible Origin of the Ultrahigh- Energy Cosmic Ray and the TeV Photon Paradoxes"

• Extragalactic cosmic rays with $E > 4 \times 10^{19} eV$ should be stopped (GKZ) by microwave background ($10^{-3} - 10^{-4} eV$) photons: $p + \gamma \to p + \pi$; and ultra-energetic γs with $E \sim 10 - 20\, TeV$ from BL Lac blazars expected to be stopped by IR background ($10^{-1} eV$), $\gamma + \gamma \to e^+ + e^-$.

• Tiny hypothesized violations of Lorentz invariance (e.g., in noncommutative and q-deformed settings) might shift the relevant thresholds and allow paradoxical events by modifying the energy-momentum dispersion law, $E = \sqrt{m2 + p2}$.

$\rightsquigarrow$ Demonstration that a class of such models (Chen & Yang) cannot work:

- The underlying theory does not really dictate the modified dispersion law proposed.
- The dispersion utilized is plagued by tachyons and so violates causality/positivity.
- Such photons would usually decay in flight by themselves, $\gamma \to e^+ + e^-$.
- The data are not that paradoxical: at the most, punch-through—but the relevant thresholds are not displaced.

- Ongoing work with Y Brihaye and C Hill: Discovered upper bound for gauged Skyrmeon masses (which arise out of deconstructive reduction of 4+1 gauge theories).

- Unlike conventional gauged Skyrmeons, whose mass increases indefinitely with the coupling of the Skyrme term, upon gauging of the diagonal product ("isospin"), all masses of simple Skyrmeons are **bounded above** by 12.932 v/g.

The Skyrme coupling does not enter in this bound, and their masses are like those of monopoles!

- This might well facilitate all cosmological estimates where this configuration is relevant.

Additional Topics

Work has been done in other subjects, not discussed in this talk:

J. S. Lee, A. Pilaftsis, M. Carena, S. Y. Choi, M. Drees, J. R. Ellis and C. E. M. Wagner,
"CPsuperH: A computational tool for Higgs phenomenology in the minimal supersymmetric standard model with explicit CP violation,"
Comput. Phys. Commun. **156**, 283 (2004)

M. Carena, A. Delgado, E. Ponton, T. M. P. Tait and C. E. M. Wagner,
"Precision electroweak data and unification of couplings in warped extra dimensions",
Phys. Rev. D **68**, 035010 (2003)

E. W. Kolb, G. Servant and T. M. P. Tait,
"The radionactive universe,"
JCAP **0307**, 008 (2003)

Present Situation and Outlook

- Theory Group has kept a vigorous and broad research program.
- In the last years theory group has been highly productive in many relevant areas of Physics.
- Efforts are being made to keep a high profile in the HEP program, emphasizing interactions with the Argonne experimenters working at the Tevatron, LHC and in Neutrino Physics.
- Very important: Start of a Junior Scientist Program, which could allow good young people to stay for a long term.